Standardized Contracts with Swing for the Market-Supported Procurement of Energy and Reserve

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Presentation outline

- Motivation & related research
- Potential advantages of standardized contracts with swing
- Example template for standardized contracts with swing
- Standardized contract trading via linked DAM/RTM markets
- Numerical example

References:

Motivation: Important needs in current power markets

- Need better ways to compensate flexibility in energy/reserve provision
  - Flexibility increasingly important with increased penetration of variable energy resources (VERs) such as wind and solar power
  - Appropriate compensation difficult under current market rules

- Need to ensure an even playing field for all market participants
  - VERs, energy storage devices (ESDs), load-serving entities (LSEs), demand response resources (DRRs), thermal generators, ...
  - Rigid requirements of service provision hinder market participation

- Need to reduce dependence on out-of-market (OOM) compensation
  - OOM increases the complexity of market rules
  - OOM increases opportunities for gaming of market rules
The importance of flexible energy/reserve provision

Figure 1: Day-ahead generation scheduling vs. real-time load-balancing needs
Previous related research


   - Suggests heavier reliance on option contracts (two-part pricing)


   - Conceptual study
   - Proposes separate contract forms (with swing) for energy & reserve
   - Proposes linked forward markets to support contract trading
Potential advantages of standardized contracts with swing

Standardized contracts with swing (flexibility) in contractual terms

- Permit offering of flexibility in service provision
- Function as forward contracts for securing future availability of energy and reserve services
- Function as blueprints for efficient balancing of real-time net load
- Permit two-part pricing for appropriate market compensation of availability and performance
  - Compensation for service *availability* via contract offer price
  - Compensation for services *performed* via performance payment method included among contractual terms
Standardized contract with swing: Example template

\[ SC = [k, d, T_{ex}, T_{pb}, T_{pe}, R_C, P_C, \phi] \]

\( k = \) Location where down/up power delivery is to occur

\( d = \) Direction (down or up)

\( T_{ex} = [t_{ex}^{min}, t_{ex}^{max}] = \) Interval of possible exercise times \( t_{ex} \)

\( T_{pb} = [t_{pb}^{min}, t_{pb}^{max}] = \) Interval of possible controlled power begin times \( t_{pb} \)

\( T_{pe} = [t_{pe}^{min}, t_{pe}^{max}] = \) Interval of possible controlled power end times \( t_{pe} \)

\( R_C = [-r^D, r^U] = \) Interval of possible controlled down/up ramp rates \( r \)

\( P_C = [p^{min}, p^{max}] = \) Interval of possible controlled power levels \( p \)

\( \phi = \) Performance payment method for real-time service performance
Example: Standardized contract with power & ramp swing
Hierarchical structure of SC forms

Figure 2: Nested hierarchy of SCs
Two-part pricing of SCs

- SC issuers can seek appropriate *ex-ante* compensation for *flexible service availability* through their *SC offer prices*.

- SC issuers can seek appropriate *ex-post* compensation for *flexible service performance* through their *performance payment methods*.
  - Each SC includes a performance payment method among its contractual terms.
### Table: Proposed ISO-managed day-ahead and real-time markets

<table>
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<tr>
<th>Market Type</th>
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<th>Decision Variables</th>
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**Figure 3:** Proposed ISO-managed day-ahead and real-time markets
SC settlement time-line for operating hour H

- ISO commits procurement payments to SC suppliers for all cleared SCs

Day Ahead Market (DAM)

DAY D-1

- ISO commits procurement payments to SC suppliers for all cleared SCs

Real Time Market (RTM)

DAY D

- ISO makes procurement & performance payments to SC suppliers

Hour H

- LSEs with DAM-cleared SC demand bids in price-responsive form pay their bid prices for these contracts
- All residual procurement/performance costs are allocated to market participants in accordance with cost allocation rules (e.g., LSEs are charged shares of these costs in proportion to the real-time loads of their customers)
RTM operations with SC trading: Numerical example

GenCo1 Offers GenPorts
GenCo2 Offers GenPorts
GenCo3 Offers GenPorts

ISO

ISOPort1, ISOPort2, ..., ISOPortK

Forecasted Net Load Profile

Reserve Requirement

Cost Minimization

ISOPort *

Operation

GenCo: Generation Company
GenPort : Portfolio of SCs
GenPort = \{SC1 ,..., SCj\}

ISOPort: Portfolio of GenPorts
ISOPort = \{Genport1,x ,..., GenPort3,y\}

ISO can choose at most one GenPort from each GenCo to construct each ISOPort
DAM and RTM linkages: Numerical example

- Optimal ISOPort selection in the RTM takes the form

\[ ISOPort^* = \{GenPort_{1}^*, GenPort_{2}^*, GenPort_{3}^* \mid \text{Contract Inventory} \} \]

- Contract Inventory = All SCs previously procured in the DAM.

- Expected total avoidable cost of ISOPort* consists of two parts:

  (i) Expected performance payments arising from the expected exercise and/or use of the SCs in the contract inventory;

  (ii) Procurement payments and expected performance payments arising from the RTM-procurement of the SCs comprising GenPort_{1}^*, GenPort_{2}^*, and GenPort_{3}^*.

Note: The DAM procurement cost is a sunk cost at the time of the RTM.
Optimal RTM ISOPort selection: Numerical example

- RTM occurs immediately prior to operating hour H on day D
- For simplicity of exposition, assume no line congestion, no line losses, and no price-sensitive load

Figure 4: RTM ISO-forecasted net load profile for hour H of day D
RTM numerical example...continued

- RTM participants: Three dispatchable GenCos, non-dispatchable Variable Energy Resources (VERs), and an ISO

- Physical attributes of the three dispatchable GenCos:

  G1: \( r_1^D = r_1^U = 120 \text{MW/minute}, \ Cap_1^{min} = 0 \text{MW}, \ Cap_1^{max} = 600 \text{MW} \)

  G2: \( r_2^D = r_2^U = 200 \text{MW/minute}, \ Cap_2^{min} = 0 \text{MW}, \ Cap_2^{max} = 700 \text{MW} \)

  G3: \( r_3^D = r_3^U = 300 \text{MW/minute}, \ Cap_3^{min} = 0 \text{MW}, \ Cap_3^{max} = 900 \text{MW} \)

- ISO objective:
  - Minimize expected total costs subject to power balance constraints, reserve requirements, and ISO-forecasted net load profile
Assume all SC performance payment methods take the simple form of a specified energy price $\phi$ ($/\text{MWh}$)

**G1’s supply offer includes two GenPorts, each with one SC:**

- **GenPort$_{1,1} = \{SC_{1,1}\}$$ at offer price v$_{1,1}$,**
  \[
  SC_{1,1} = [t_{pb} = 0, \ t_{pe} = 60, \ |r| \leq 100, \ 0 \leq p \leq 500, \ \phi = 100]
  \]  

- **GenPort$_{1,2} = \{SC_{1,2}\}$$ at offer price v$_{1,2}$,**
  \[
  SC_{1,2} = [t_{pb} = 0, \ t_{pe} = 60, \ |r| \leq 120, \ 0 \leq p \leq 500, \ \phi = 105].
  \]
G2’s supply offer includes three GenPorts with multiple SCs:

\[ \text{GenPort}_{2,1} = \{ \text{SC}_{2,1,1}, \text{SC}_{2,1,2} \} \text{ at offer price } v_{2,1}, \quad (3) \]

\[ \text{SC}_{2,1,1} = [t_{pb} = 10, t_{pe} = 20, |r| \leq 200, 0 \leq p \leq 600, \phi = 135] \]
\[ \text{SC}_{2,1,2} = [t_{pb} = 30, t_{pe} = 60, |r| \leq 200, 0 \leq p \leq 600, \phi = 130] \]

\[ \text{GenPort}_{2,2} = \{ \text{SC}_{2,2,1}, \text{SC}_{2,2,2}, \text{SC}_{2,2,3} \} \text{ at offer price } v_{2,2}, \quad (4) \]

\[ \text{SC}_{2,2,1} = [t_{pb} = 0, t_{pe} = 10, |r| \leq 100, 0 \leq p \leq 100, \phi = 105] \]
\[ \text{SC}_{2,2,2} = [t_{pb} = 10, t_{pe} = 20, |r| \leq 200, 0 \leq p \leq 600, \phi = 135] \]
\[ \text{SC}_{2,2,3} = [t_{pb} = 30, t_{pe} = 60, |r| \leq 200, 0 \leq p \leq 600, \phi = 130] \]

\[ \text{GenPort}_{2,3} = \{ \text{SC}_{2,3,1}, \text{SC}_{2,3,2}, \text{SC}_{2,3,3} \} \text{ at offer price } v_{2,3}, \quad (5) \]

\[ \text{SC}_{2,3,1} = [t_{pb} = 0, t_{pe} = 10, |r| \leq 100, 0 \leq p \leq 100, \phi = 105] \]
\[ \text{SC}_{2,3,2} = [t_{pb} = 10, t_{pe} = 20, |r| \leq 200, 0 \leq p \leq 700, \phi = 140] \]
\[ \text{SC}_{2,3,3} = [t_{pb} = 30, t_{pe} = 60, |r| \leq 200, 0 \leq p \leq 700, \phi = 135] \]
G3’s supply offer includes two GenPorts, each with three SCs:

GenPort$_{3,1} =$\{SC$_{3,1,1}$, SC$_{3,1,2}$, SC$_{3,1,3}$\} at offer price $v_{3,1}$, \hspace{1cm} (6)

SC$_{3,1,1} = [t_{pb} = 10, \ t_{pe} = 20, \ |r| \leq 300, \ 0 \leq p \leq 900, \ \phi = 175]$  
SC$_{3,1,2} = [t_{pb} = 33, \ t_{pe} = 39, \ |r| \leq 200, \ 0 \leq p \leq 400, \ \phi = 155]$  
SC$_{3,1,3} = [t_{pb} = 48, \ t_{pe} = 54, \ |r| \leq 200, \ 0 \leq p \leq 400, \ \phi = 155]$  

GenPort$_{3,2} =$\{SC$_{3,2,1}$, SC$_{3,2,2}$, SC$_{3,2,3}$\} at offer price $v_{3,2}$, \hspace{1cm} (7)

SC$_{3,2,1} = [t_{pb} = 10, \ t_{pe} = 20, \ |r| \leq 300, \ 0 \leq p \leq 900, \ \phi = 175]$  
SC$_{3,2,2} = [t_{pb} = 30, \ t_{pe} = 39, \ |r| \leq 200, \ 0 \leq p \leq 400, \ \phi = 150]$  
SC$_{3,2,3} = [t_{pb} = 44, \ t_{pe} = 54, \ |r| \leq 200, \ 0 \leq p \leq 400, \ \phi = 150]$
Power balance constraint for ISO

- ISO’s forecasted net load profile for operating hour H must be balanced.

Figure 5: ISO-forecasted net load profile for hour H
Cleared ISOPort must achieve a *Zero Balance Gap (ZBG)* for hour H

**Figure 6:** ZBG achieved by ISOPort_2 = (GenPort_{1,1}, GenPort_{2,3}, GenPort_{3,1})
Multiple ISOPorts might be able to achieve a ZBG.

Attaining a ZBG is a necessary but not sufficient condition for an ISOPort to be optimal.

ISO must also consider the “reserve range” and expected total cost of an ISOPort.
Reserve Range (RR) inherent in ISOPorts with swing

Figure 7: Reserve Range (RR) for ISOPort_2 during hour H of day D
Reserve range constraint for ISO

- Reserve Range $RR(\alpha^*) = \text{Power corridor around ISO-forecasted net load profile } L^F$ with width determined by $\alpha^* = (\alpha^{D*}, \alpha^{U*})$

- The required amount of down-power reserve is determined by $\alpha^{D*}$ and the required amount of up-power reserve is determined by $\alpha^{U*}$

- For each operating minute $M$:

$$RR_M(\alpha^*) = [RR^\text{min}_M(\alpha^*), RR^\text{max}_M(\alpha^*)]$$

$$RR^\text{min}_M(\alpha^*) \leq [1 - \alpha^{D*} ] L^F_M \leq L^F_M \leq [1 + \alpha^{U*} ] L^F_M \leq RR^\text{max}_M(\alpha^*)$$
Expected total cost of ISOPort

- Expected total cost of ISOPort = (GenPort₁, GenPort₂, GenPort₃) satisfying ZBG and RR(α*) constraints consists of:

  (i) the portfolio offer prices \{v₁, v₂, v₃\} paid to G1, G2, and G3 for GenPort₁, GenPort₂, and GenPort₃

  (ii) the expected total performance payments to be paid to G1, G2, and G3 for energy to satisfy the ZBG constraint.
Calculation of expected total performance payments for an ISOPort

- Shaded Area(SC) \times \phi(SC) = \text{expected performance payment (SC)}
ISOPort optimization $\rightarrow$ energy/reserve co-optimization

- ISOPort expected total cost minimization subject to ZBG and $\text{RR}(\alpha^*)$ constraints ensures energy/reserve co-optimization for hour $H$:
  
  - The ZBG constraint ensures balancing of the ISO forecasted net load profile for hour $H$
  
  - The $\text{RR}(\alpha^*)$ constraint ensures sufficient availability of generation capacity to cover a power corridor around the ISO-forecasted net load profile for hour $H$ whose width is determined by $\alpha^*$
Summary of key findings for the SC system

- permits full, separate, market-based compensation for service availability and service performance (FERC Order 755)
- facilitates a level playing field for market participation.
- facilitates co-optimization of energy and reserve markets
- supports forward-market trading of energy and reserve
- permits service providers to offer flexible service availability.
- provides system operators with real-time flexibility in service usage
facilitates accurate load forecasting and following of dispatch signals
permits resources to internally manage UC and capacity constraints
permits the robust-control management of uncertain net load
eliminates the need for out-of-market payment adjustments
reduces the complexity of market rules
Future work

- Seek efficient solution methods for SC robust-control optimization
  - ISO’s optimal choice of an SC portfolio (ISOPort) for an operating day D is a *topological covering problem*
  - Requires minimizing the expected total cost of covering an appropriate reserve range \( RR_k(\alpha^*) \) around the forecasted net load profile for each bus \( k \)

- Undertake detailed SC system studies to test
  - feasibility
  - efficiency (non-wastage of resources)
  - reliability (security/adequacy)
  - robustness against strategic manipulation